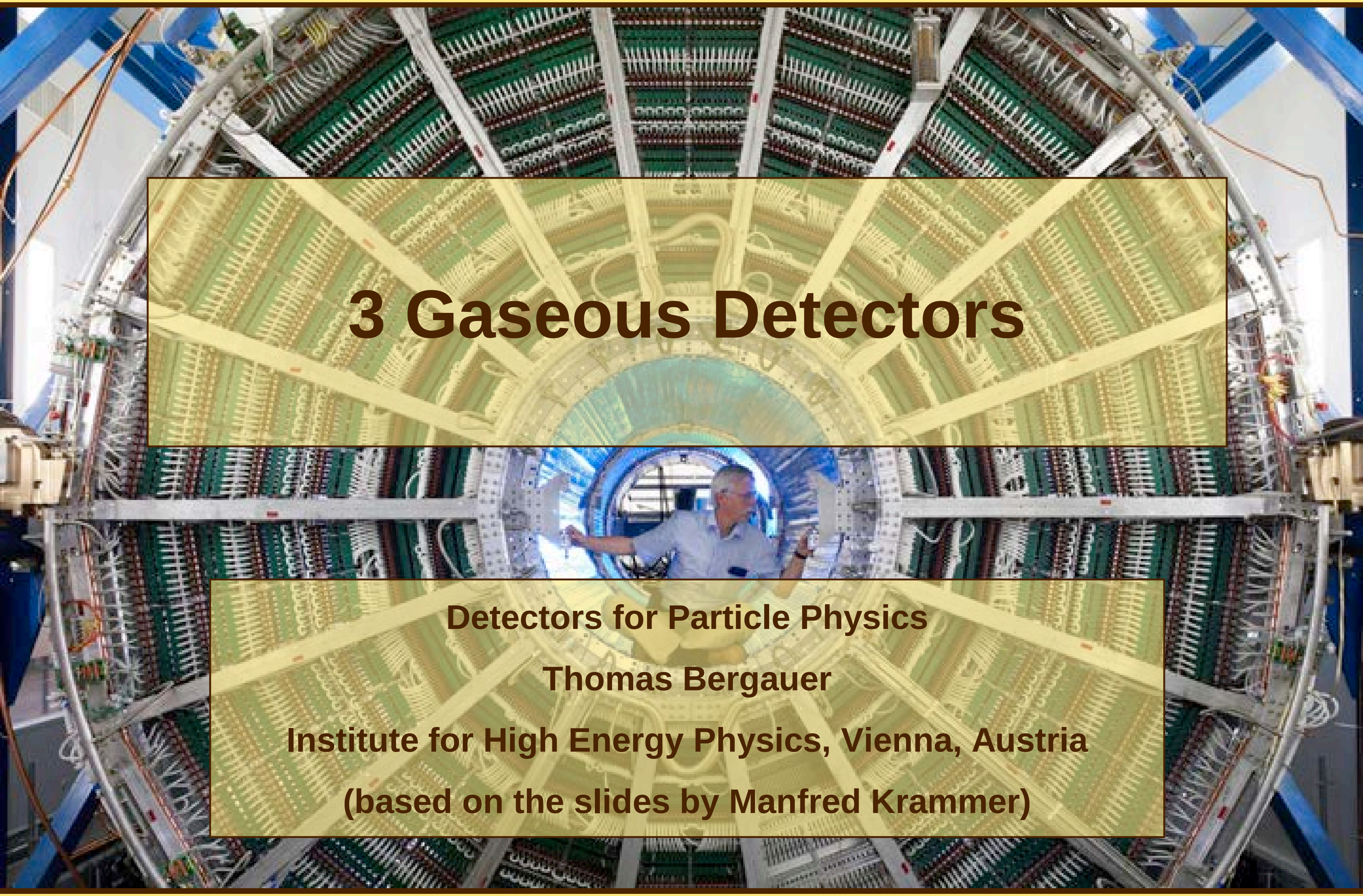

# 3 Gaseous Detectors

**Detectors for Particle Physics**


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**(based on the slides by Manfred Krammer)**

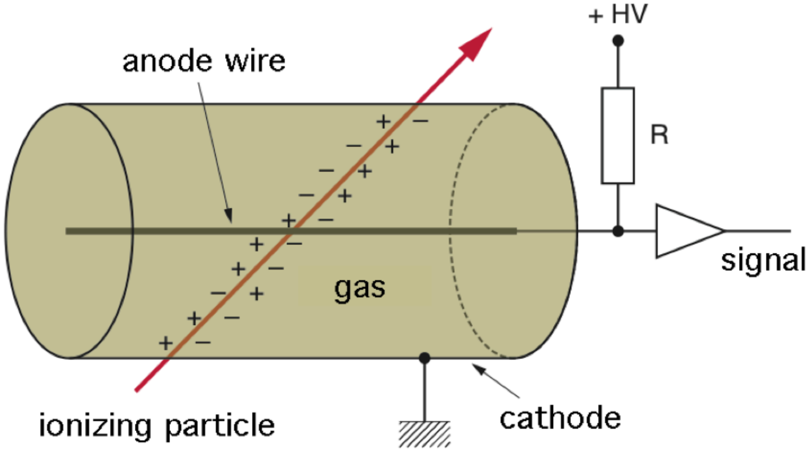
# 3 Gaseous Detectors

## Content

## Properties of gaseous detectors

- ★ Charged particles penetrating a gas volume ionise atoms, and hence produce electron ion pairs. The average number of primary electron ion pairs produced is proportional to the dE/dx of the particle.
- ★ Electrons and ions drift in an externally applied electric field
- ★ Due to the high mobility of electrons and ions, gases are ideal detectors.
- ★ The drift of the electrons and ions induce the signal (not the collection of charge at the electrodes). True in all other detector types as well!

A simple wire chamber:
Gas filled cylinder with an anode wire.
The cylinder surface is the cathode.




The applied voltage $V$ creates an electric field $E$. For this geometry the field is:

$$\boxed{E(r) = \frac{1}{r}\frac{V}{\ln(b/a)}}$$

$r$ … distance from the wire
$a$ … radius of anode wire
$b$ … radius of cathode cylinder

If the field close to the anode wire is high enough secondary ionization multiplies the signal!

## Diffusion of electrons and ions

- ★ In the absence of an external field the electrons and ions **move uniformly** away from the point of creation due to disordered thermal movement (Brownian movement) → diffusion.
- ★ The electrons and ions loose energy by multiple scattering until thermal equilibrium is reached.

At room temperature:

$e^-$ $v_{diff} \approx 10^6$ cm/s

ions $v_{diff} \approx 10^4$ cm/s

Mean diffusion velocity:

$$\boxed{v_{\text{diff}} = \sqrt{\frac{8\,kT}{\pi\, m}}}$$

$m$ .. mass of $e^-$ or ion

# 3.2 Diffusion and Drift
## Diffusion coefficient, free path length

The diffusion coefficient is determined by the average free path length $\lambda$ of $e^-$ and ions in the gas:

$$D = \frac{1}{3} v_{\mathrm{diff}} \lambda$$

$v_{\mathrm{diff}}$ … average diffusion velocity

For a classical, ideal gas $\lambda$ is:

$$\lambda = \frac{1}{\sqrt{2}} \frac{kT}{\sigma p}$$

$p$ … gas pressure, T …temperature,

$k$ … Boltzmann constant, $k = 1.3807 \cdot 10^{-23}$ J/K

$\sigma$ … total cross section for collision with a gas molecule

# 3.2 Diffusion and Drift

## Charge carrier distribution

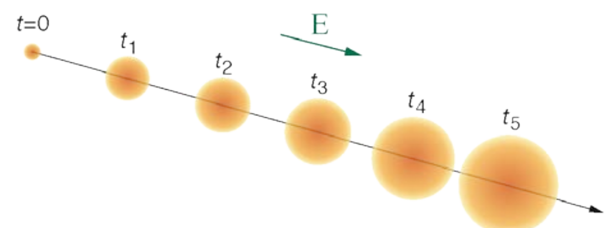
The charge carrier distribution follows a Gauss distribution:

$$\boxed{\frac{dN}{dx} = \frac{N_0}{\sqrt{4\pi Dt}} \exp\left(-\frac{x^2}{4Dt}\right)}$$

$N$ … number of free charged carriers
$x$ … distance from point of creation
$t$ … time after creation
$D$ … diffusion coefficient

The width (rms - root mean square) of the distribution is (linear diffusion):

$$\boxed{\sigma_x = \sqrt{2Dt}}$$




and for volume diffusion (spherical dispersion):

$$\boxed{\sigma_{\text{vol}} = \sqrt{3} \cdot \sigma_x = \sqrt{6Dt}}$$

# 3.2 Diffusion and Drift

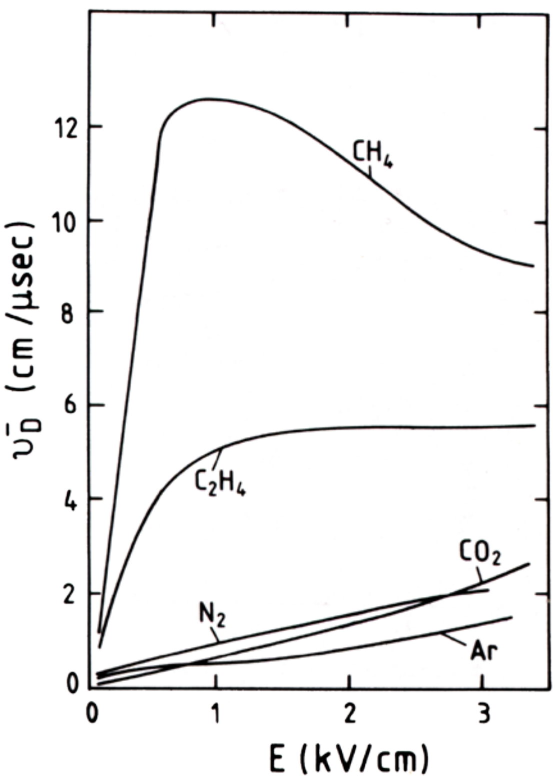
## Drift velocity - 1

- ★ If an **external electric field** is applied the electrons and ions are accelerated and move along the field lines → drift
- ★ The drift is superimposed onto the diffusion movement
- ★ Acceleration is interrupted by collision with gas atoms, this limits the drift velocity → mean drift velocity $v_D$

$$\boxed{\vec{v}_D = \frac{q}{m} \cdot \tau(\vec{E},\sigma) \cdot \vec{E} \cdot \frac{p_0}{p} = \mu \cdot \vec{E} \cdot \frac{p_0}{p}}$$

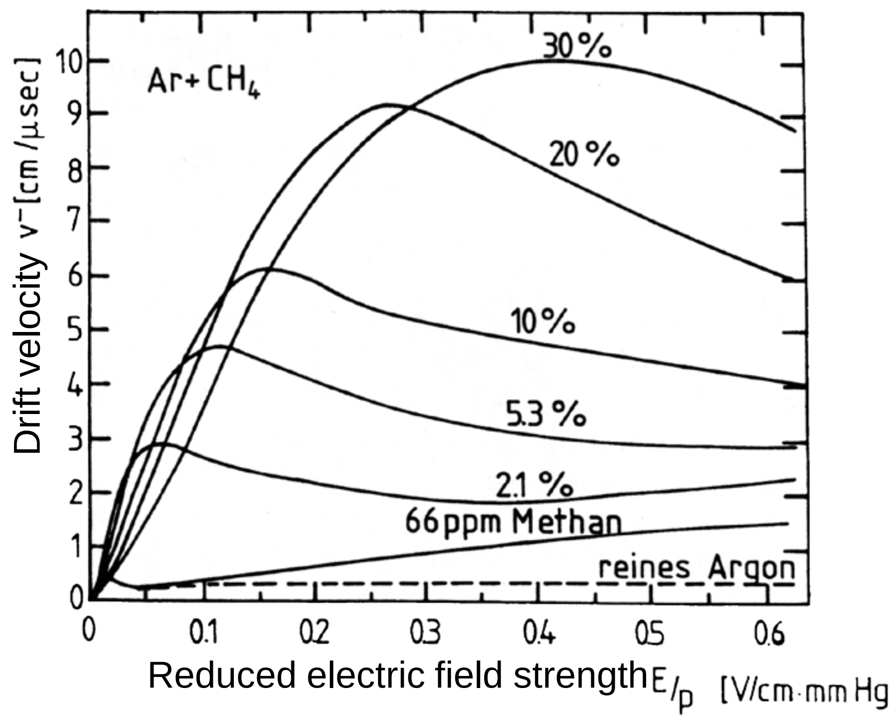
*q, m* … charge and mass
$E$ … electric field
$\tau$ … mean time between collisions
$p$ … gas pressure, $p_0$ … standard pressure
$\mu$ … mobility, $\mu = \tau \cdot q/m$,

Drift velocity of electrons for different gases (STP):




K. Kleinknecht, *Detektoren für Teilchenstrahlung*, B.G. Teubner, 1992

Drift velocity of electrons for various Argon Methan gas mixtures:

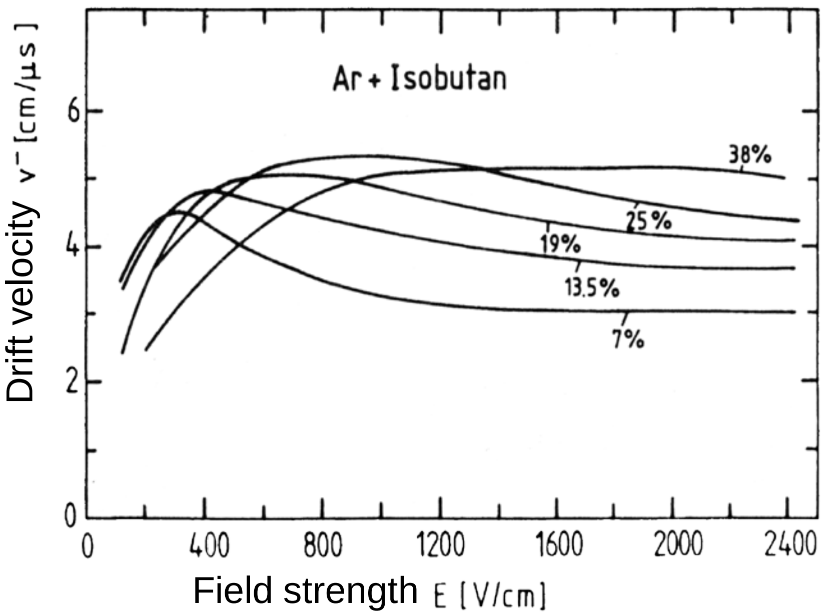



C. Grupen, *Teilchendetektoren*, B.I. Wissenschaftsverlag, 1993

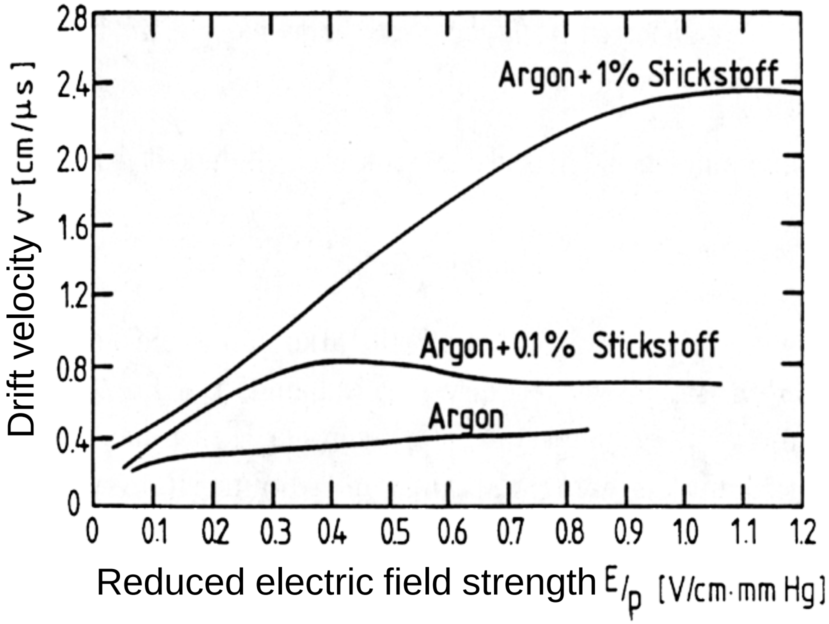
# 3.2 Diffusion and Drift

## Drift velocity in different gases - 2

Drift velocity of electrons in Argon Isobutane mixtures (1 atm):




Drift velocity of electrons in Argon without / with admixture of $N_2$:




Both plots: C. Grupen, *Teilchendetektoren*, B.I. Wissenschaftsverlag, 1993

## Influence of an external magnetic field

Magnetic fields modify the flight path of the charge carriers. In addition to the drift direction following the electric field lines, the Lorentz force forces the charge carriers between two collisions onto circular or spiral trajectories.

The mean drift velocity $v_D$ becomes:

$$\boxed{\vec{v}_D = \frac{\mu}{1+\omega^2\tau^2} \cdot \left( \vec{E} + \frac{\vec{E} \times \vec{B}}{B} \omega\tau + \frac{\left(\vec{E} \cdot \vec{B}\right) \cdot \vec{B}}{B^2} \omega^2\tau^2 \right)}$$

$E$ … external electric field

$\mu$ … mobility of charge carriers, $\mu = \tau \cdot q/m$

$q, m$ … charge, mass of charge carriers

$B$ … external magnetic field

$\omega$ … cyclotron frequency, $\omega = B \cdot q/m$

$\tau$ … mean time between collisions

Special case that electric and magnetic field are perpendicular:

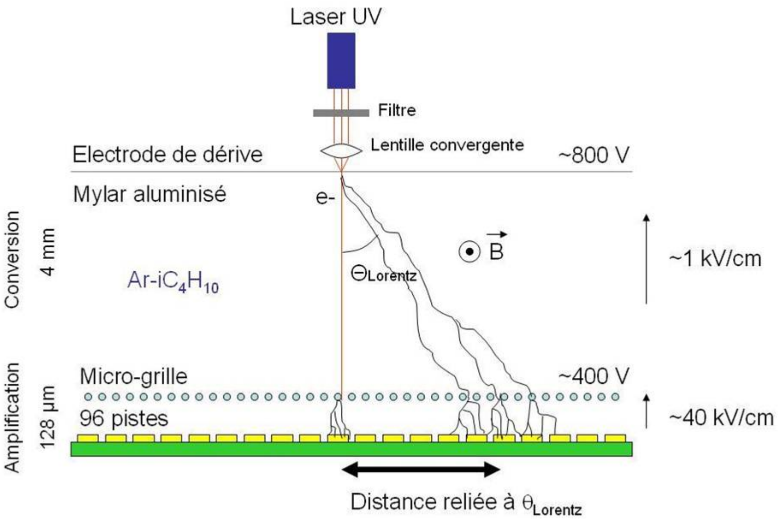
$$\boxed{v_D = \left|\vec{v}_D\right| = \frac{\mu E}{\sqrt{1+\omega^2\tau^2}}} \qquad \text{for } \vec{E} \perp \vec{B}$$

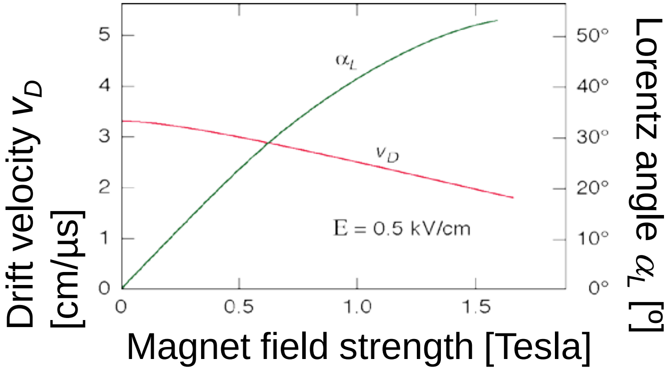
# 3.2 Diffusion and Drift
## Lorentz angle

The Lorentz angle is the angle between the direction of the electric field and the drift direction of electrons under the influence of the magnetic field.

In the case of perpendicular electric and magnetic fields, the Lorentz angle is:

$$\boxed{\tan \alpha_L = \omega\tau = v_D \frac{B}{E}}$$



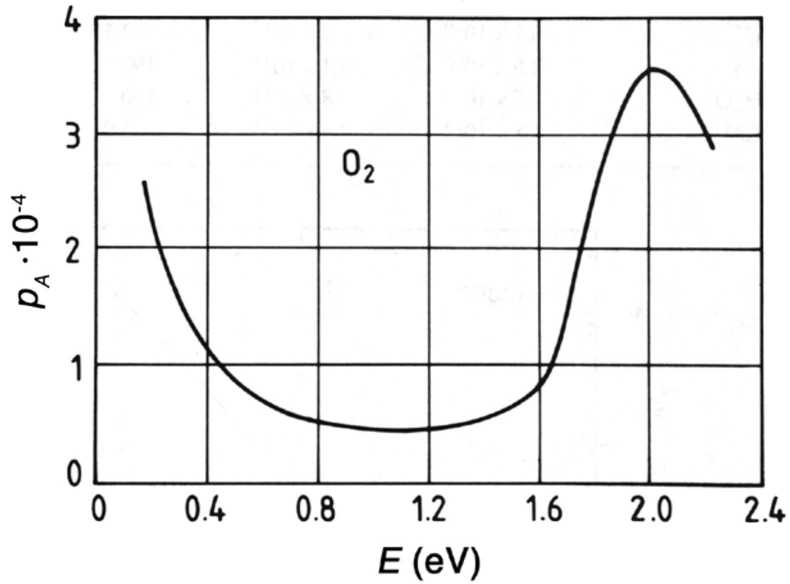




$v_D$ and $\alpha_L$ in a gas mixture of Argon (67.2%), Isobutane (30.3%) and Methylal (2.5%) for perpendicular $E$ and $B$ fields

# 3.2 Diffusion and Drift
## Electronegative gases

- ★ Electrons with energies in the eV range may become attached to gas atoms. The probability for electron attachment is called the attachment coefficient.
- ★ This effect is negligible for noble gases, $N_2$, $H_2$ und $CH_4$. Needs to be considered for electronegative gases such as $O_2$, $Cl_2$, $NH_3$ und $H_2O$.
- ★ Already small impurities (per mill) of electronegative gases cause strong deterioration of the detector performance!

Attachment coefficient of Oxygen for electrons as function of the energy (Minimum at 1 eV → Ramsauer effect):




K. Kleinknecht, *Detektoren für Teilchenstrahlung*, B.G. Teubner, 1992

# 3.3 Amplification

## First Townsend coefficient – Amplification Factor

- Primary electrons in high electric fields reach enough energy to produce ionisation → secondary electrons, they may produce further electrons → avalanche formation
- The first Townsend coefficient $\alpha$ is the number of electron/ion pairs produced by an electron per path length:

$$\boxed{\alpha = \sigma_i \cdot \frac{N_A}{V_{\mathrm{mol}}}}$$

$\sigma_i$ … Ionization cross section
$N_A$ … Avogadro's number
$V_{\mathrm{mol}}$ … Molar volume (ideal gas: 22.4 l/Mol)

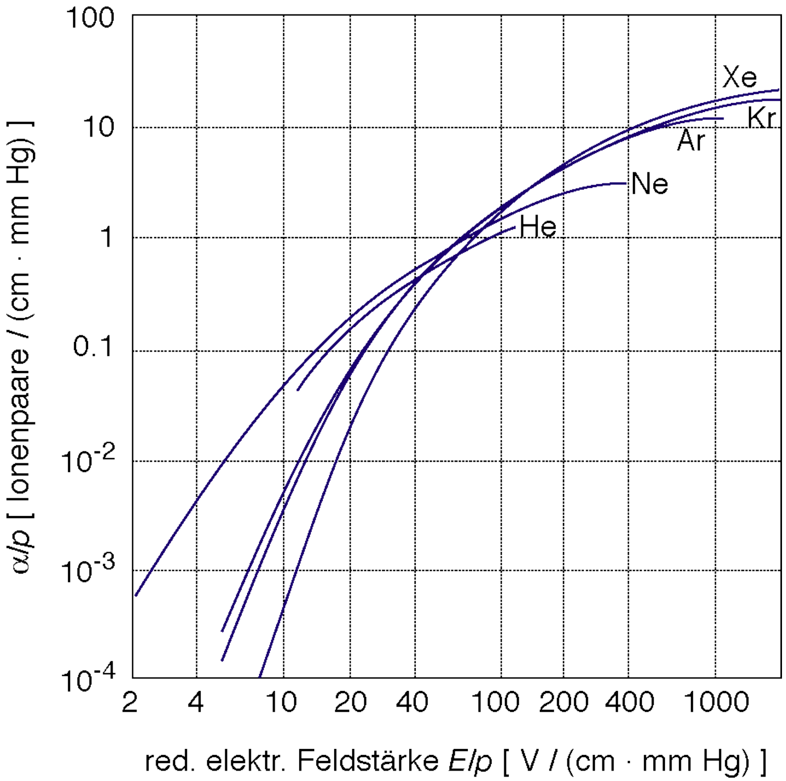
- $\sigma_i$ depends on the electron energy, the electron energy is given by the acceleration in the electric field depending on the position within the detector → $\alpha = \alpha(x)$ depends on position in the detector
- Number of produced electrons and amplification factor $A$

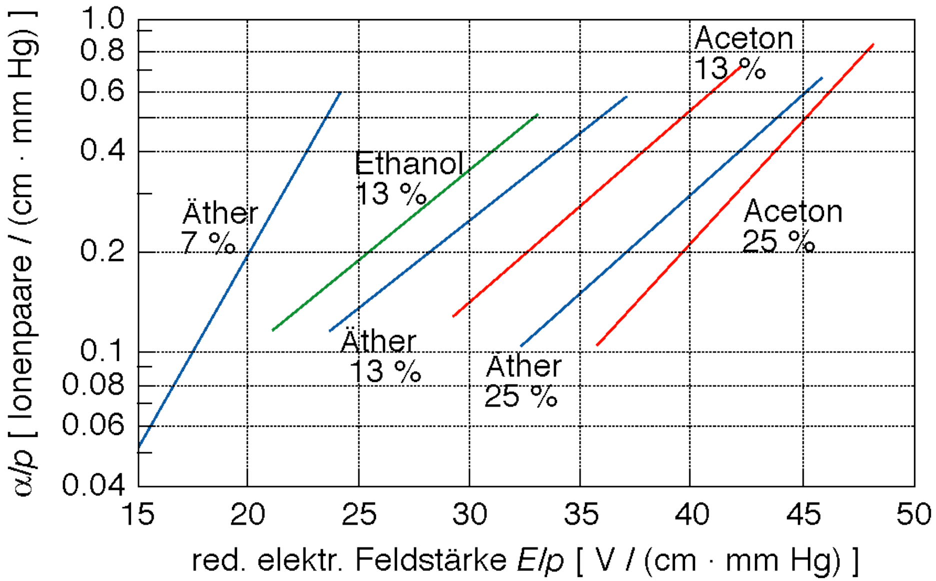
$$\boxed{N(x) = N_0 \cdot e^{\int \alpha(x)\,dx} = N_0 \cdot A}$$

$N_0$ …number of primary $e^-$

## First Townsend coefficient – Examples

First Townsend coefficient as function of the reduced electric field strength for various noble gases and Argon with different admixtures:




F. Sauli, *Principles of Operation of Multiwire Proportional and Drift Chambers*, CERN 77-09, 1977

1 mm Hg ~ 1/760 of standard atmospheric pressure

# 3.3 Amplification
## Second Townsend coefficient

- Following ionization atoms may be in an excited state and subsequently emit photons, via the photo effect additional electrons are produced.
- Probability of an electron to produce a photoelectron is called the second Townsend coefficient $\gamma$
- In the first generation the primary e$^-$ are amplified to $N_0A$ and produce $\gamma N_0 A$ photoelectrons, these are amplified in the second generation to $(\gamma N_0 A)\cdot A = \gamma N_0 A^2$ e$^-$ and create $\gamma \cdot (\gamma N_0 A^2)$ photoelectrons, etc.

$$N(x) = N_0 A_\gamma = N_0 A + N_0 A^2 \gamma + N_0 A^3 \gamma^2 + \ldots = N_0 A \cdot \sum_{k=0}^{\infty} (A\gamma)^k = \frac{N_0 A}{1 - \gamma A}$$

$A_\gamma$ … Amplification factor including photo effect

- Total number of produced electrons becomes $$N(x) = \frac{N_0 A}{1 - \gamma A}$$
- In case of $\gamma A \to 1$ the signal becomes independent from the primary ionization (at about A ≈ $10^8$)

# 3.3 Amplification
## Penning effect

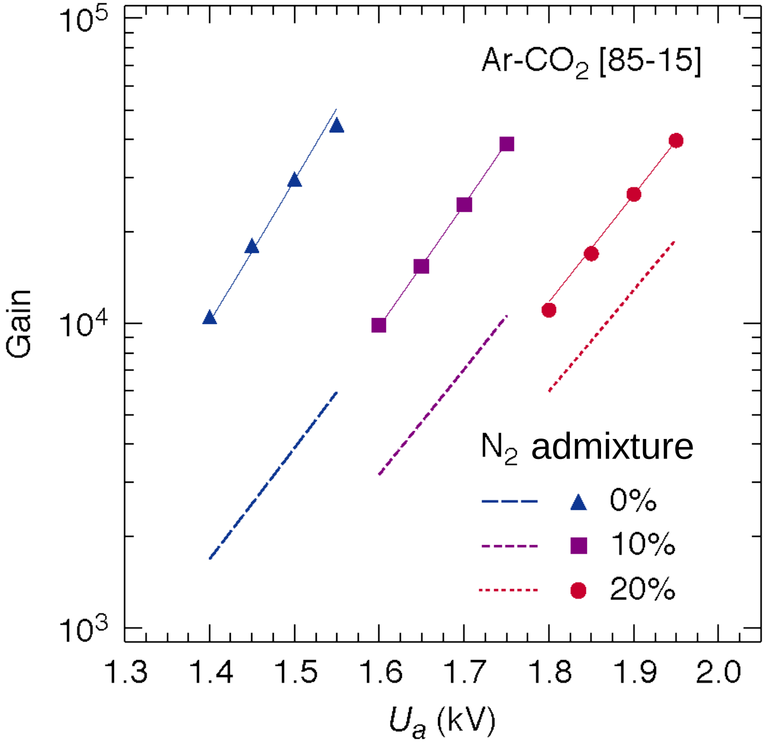
- ★ The Penning effect occurs in gas mixtures, in which a metastable excited state of one gas component is energetically higher than the ionization energy of the second gas component. The excited gas atoms/molecules ionize the second gas through collisions. → increase of the number of electron ion pairs.
- ★ Penning gas mixtures consist typically of a noble gas (in most cases Ar) and a low concentration admixture of a molecular gas.
  Example: Argon, metastable states at 11.55, 13.0, 14,0 eV
  with admixture of Isobutane $I_0$=10.7 eV

(However, excitation of vibration and rotation states in molecular gases reduces energy available for ionization.)

# 3.3 Amplification

## Penning effect - example

Amplification in a mixture of Ar (85%) and $CO_2$ (15%) with different admixtures of $N_2$:




A. Andronic et al., Nucl. Instr. Meth. A **523** , 302 (2004)

Penning effect:

$Ar^* + CO_2 \rightarrow Ar + CO_2^+ + e^-$

Points: measurements

Dashed lines: simulation without Penning effect

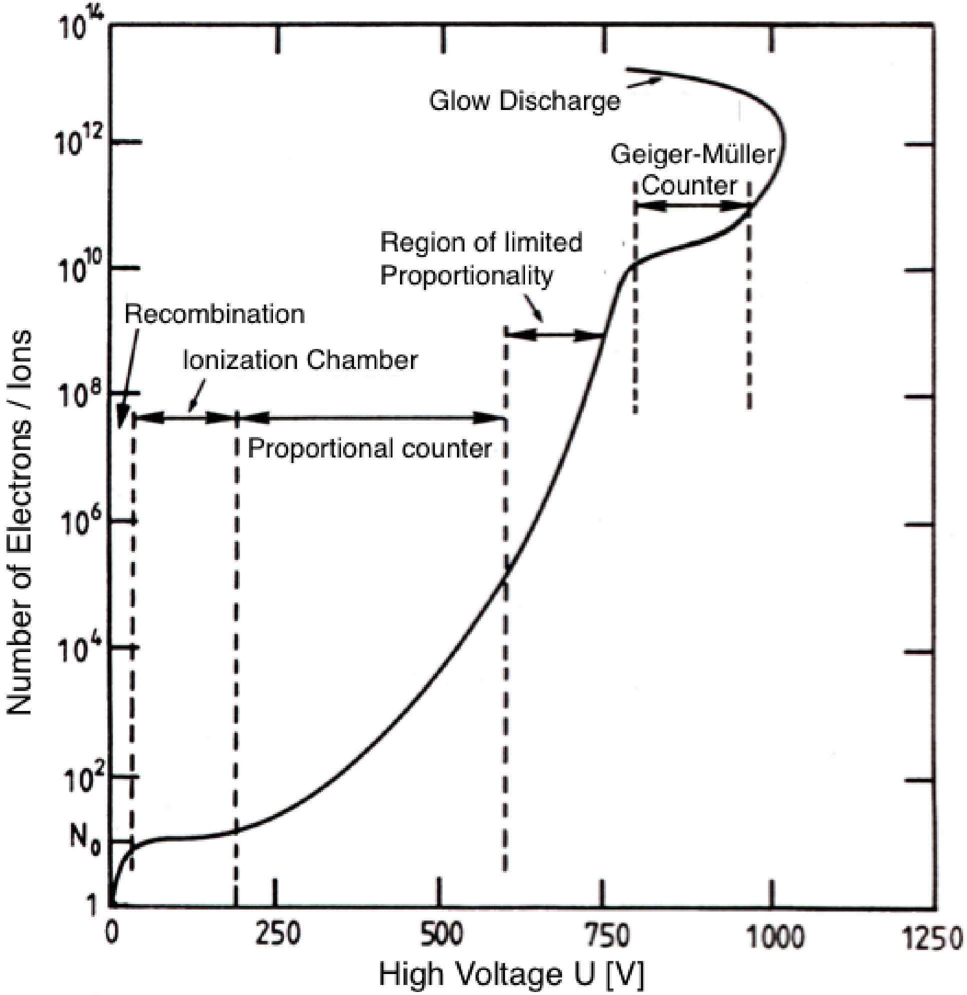
Continuous lines: simulation with Penning effect

# 3.4 Gas Counter Operation

## Operation modes

Gas counters may be operated in different operation modes depending on the applied high voltage.

E.g. operation range of a cylindrical gas counter with central anode wire as function of the high voltage; number of e⁻ ion pairs for primary ionizing electrons:



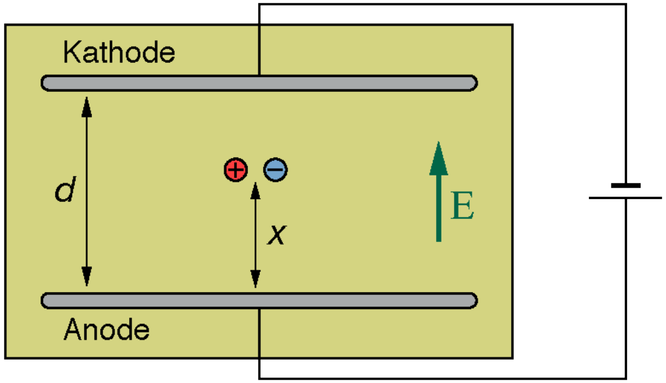

C. Grupen, *Teilchendetektoren*,
B.I. Wissenschaftsverlag, 1993
(Original: W. Price, *Nuclear Radiation Detection*, McGraw-Hill, 1958)

## Ionization chamber - 1

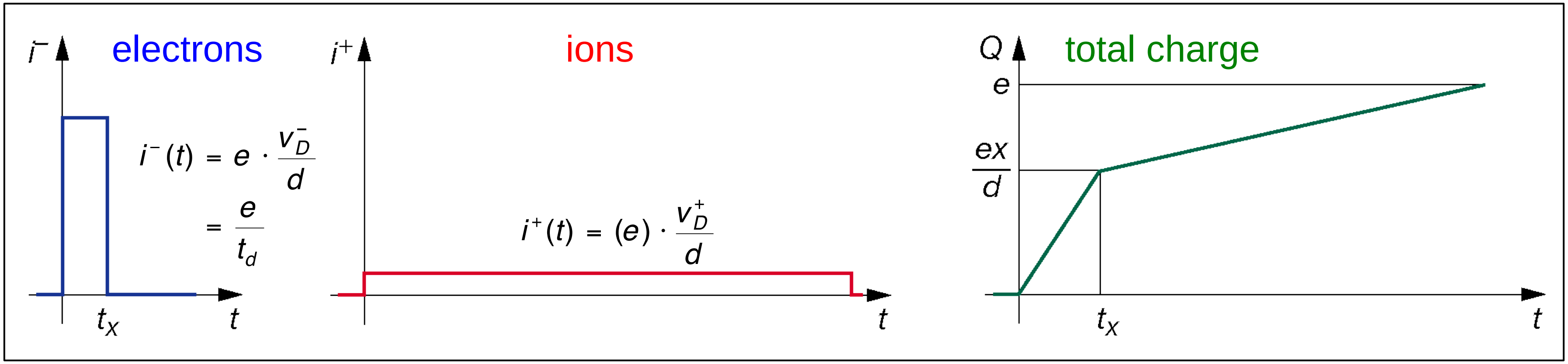
- ★ An ionization chamber is operated at a voltage which allows full collection of charges, however below the threshold of secondary ionization (no amplification).

For a typical field strength 500 V/cm and typical drift velocities the collection time for 10 cm drift is about 2 µs for e⁻ and 2 ms for the ions.

Planar ionization chambers:




Time evolution of the signal for **one e⁻ ion pair**:

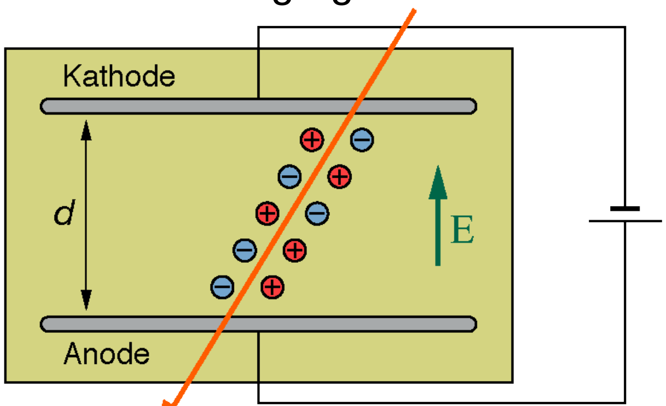


# 3.4 Gas Counter Operation
## Ionization chamber - 2

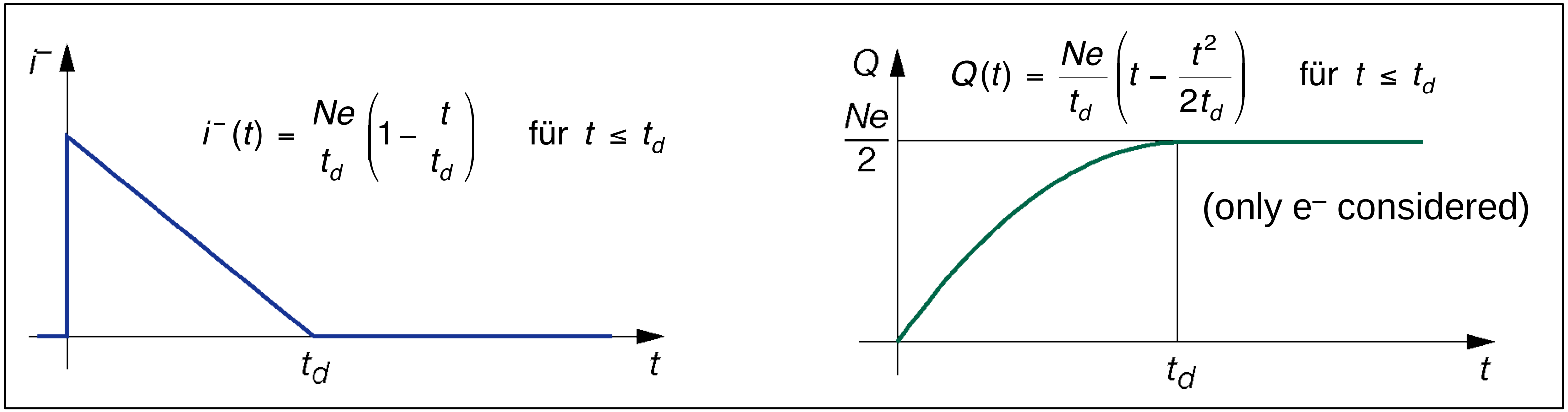
Remember:
The signal is induced by the movement of e$^-$ and ions in the electric field.

The fast drifting e$^-$ cause a short pulse, whereas the slow moving ions cause a long running current pulse.

Planar ionization chambers, continuous charge generation:




Time evolution of the signal for **continuous charge generation** (only drift of e- considered):



# 3.4 Gas Counter Operation
## Proportional mode - 1

★ Signal amplification through secondary ionization

★ The amplification factor in gas detectors operating in the proportional mode is constant → signal is proportional to the primary ionization

★ Amplification factors in proportional mode of $10^4$–$10^6$

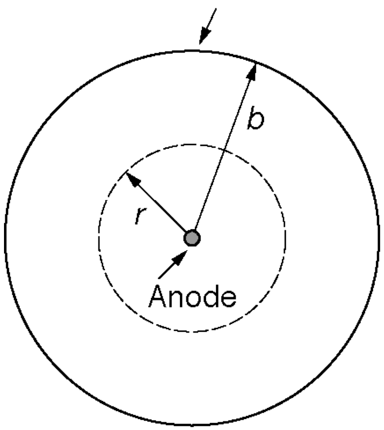
★ Limit of the proportional mode is reached when electrons produced by the photo effect are no longer negligible

★ The effect of photons is reduced with admixtures of a “quenching” gas (e.g. $CH_4$, $CO_2$). These gases absorb UV photons.

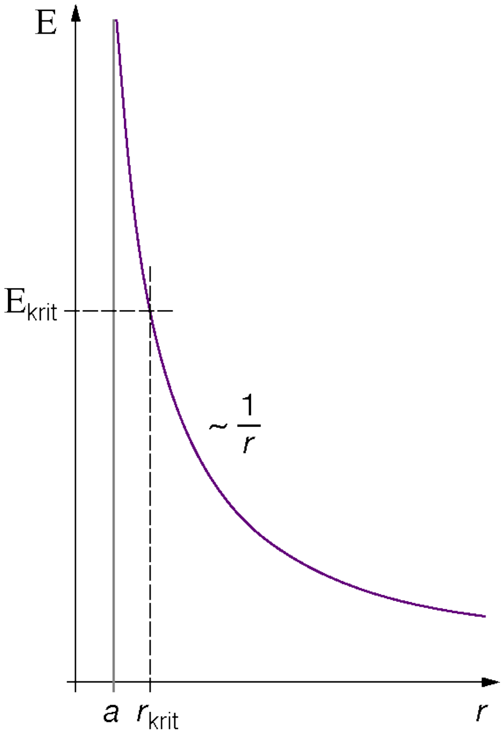
## Proportional mode - 2

- ★ Typical geometry: cylindrical cathode with thin central anode wire. Electric field in vicinity of the wire $<1/r$, at $r \leq r_{\text{krit}}$ field strength high enough to cause secondary ionization, wire diameter 20 - 100 µm.

Cross section of a proportional counter and electric field $E$ as function of the distance to the wire:



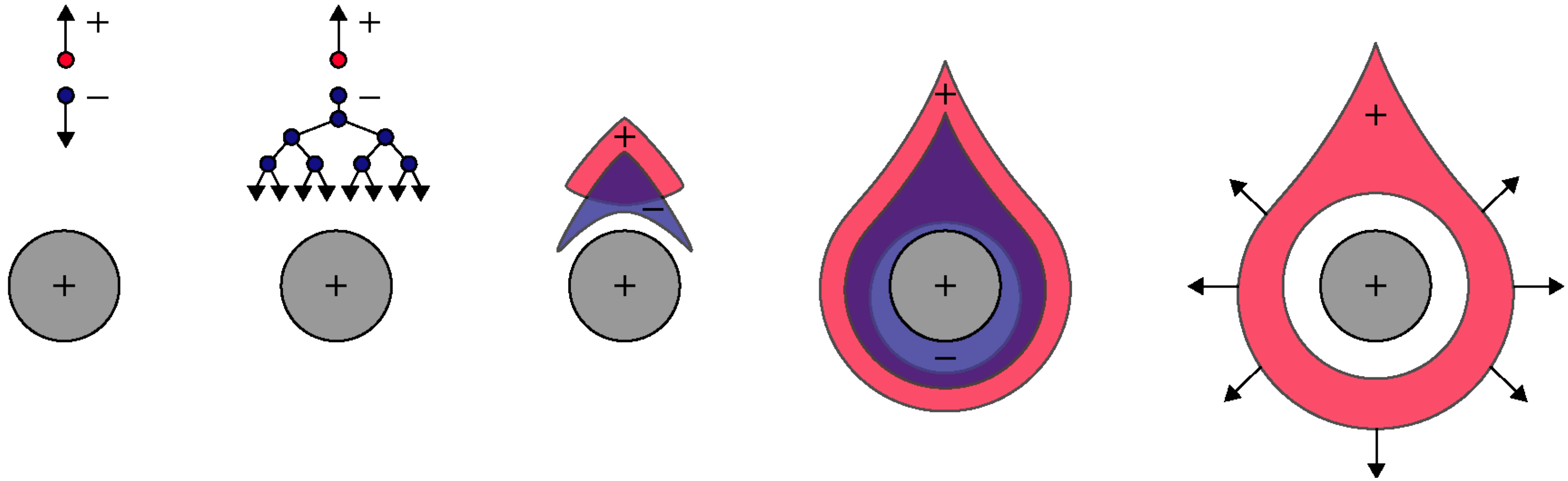

a … radius anode wire
b … radius cathode



# 3.4 Gas Counter Operation

## Amplification process around a wire

- Electrons produced by the primary particle drift towards the anode wire. They reach the area of high fields.
- As soon as the field is larger than $E_{krit}$ secondary ionization starts. A charge avalanche develops in the vicinity of the anode wire.
- The electrons drift quickly to the anode wire, whereas the positive ions slowly drift away towards the cathode.



# 3.4 Gas Counter Operation

## Time evolution in a cylindrical wire chamber

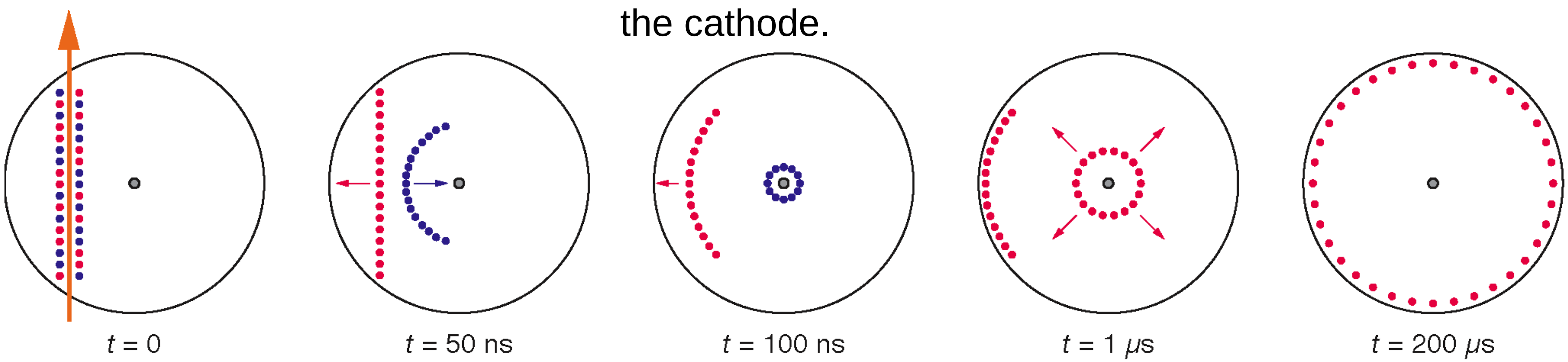
Charged particle produces primary ionization along the track.

Primary $e^-$ drift quickly to the anode wire. Ions drift much slower to the cathode cylinder.

The primary $e^-$ reach the region of high field and produce secondary ionization ➔ charge carrier avalanche around the wire. The primary ions continue to drift to the cathode.

The ions produced in the secondary ionization drift also to the cathode. The secondary $e^-$ are generated close to the anode.

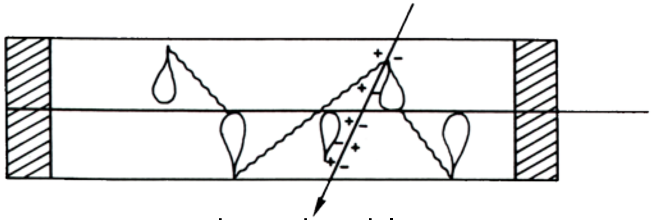
Finally also the secondary ions reach the cathode.




The induced signal is by far dominated by the movement of the ions!

# 3.4 Gas Counter Operation
## Geiger-Müller Counter

- Is the electric field large enough that $\gamma A \approx 1$ the detector is operating in the Geiger-Müller mode.
- The produced total charge is independent from the primary ionization (The charge depends only on the capacitance of the counter and the applied voltage).
- Gas amplification in Geiger-Müller mode is between $10^8$ und $10^{10}$.




C. Grupen, *Teilchendetektoren*, B.I. Wissenschaftsverlag, 1993

- The UV photons are spreading transversal to the field and create photoelectrons in the whole gas volume. The discharge is no longer localized.

# 3.4 Gas Counter Operation
## Discharge quenching

- Triggered by UV photons avalanches are created everywhere. The $e^-$ disappear quickly, whereas the positive ions create a plasma tube (space charge) along the anode wire → reduce field around the wire and prevent $e^-$ from secondary ionisation → ions drift slowly to the cathode (~ 1 ms), where they may create secondary $e^-$ → avalanche production continues.
- Discharge has to be stopped, various methods are used:
  - Charging resistor $R$ reducing the high voltage to $U_0 - IR$. Time constant $RC$ must be long enough to allow all ions to reach the cathode → detector dead time of ~10 ms.
  - Change of polarity for a short time → ions created close to the anode wire are then absorbed quickly by the negative polarity of the wire.
  - Self clearing using admixture of quencher gas, e.g. methane ($CH_4$), ethane ($C_2H_6$), isobutane ($iC_4H_{10}$), ethanol ($C_2H_5OH$) methylal ($CH_2(OCH_3)_2$). The absorption of UV photons reduces their range to few hundred µm close to the anode wire → lower $R$ possible →shorter dead time ~ 1 µs

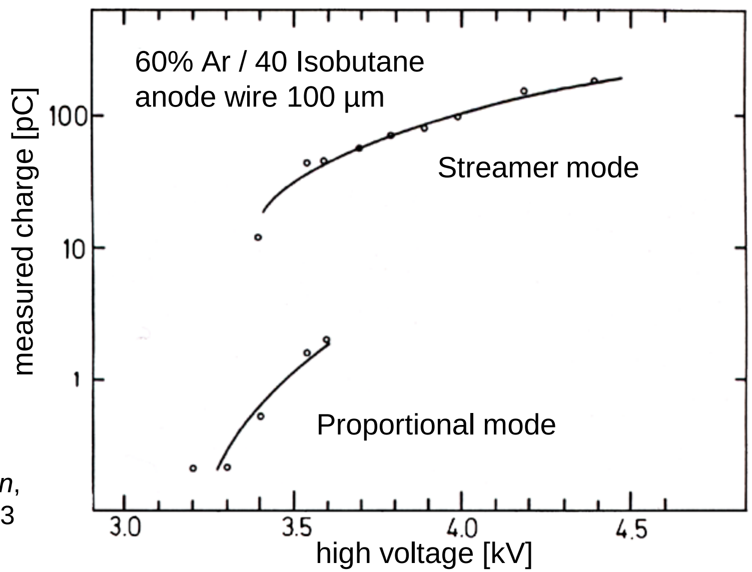
# 3.4 Gas Counter Operation

## Streamer tubes

- Streamer mode: high fields and gas mixtures with large fraction of quenching gases to suppress the lateral extend of the discharge → localized discharge with very large signals
- Gas amplification in streamer mode $\geq 10^{10}$.
- A typical gas mixture: argon (≤ 60%), isobutane (≥ 40%).
- Total charge signal is independent of primary ionization (non-proportional).

In the transition region from proportional to streamer mode both signals may exist simultaneously:

Measured charge as function of applied high voltage:



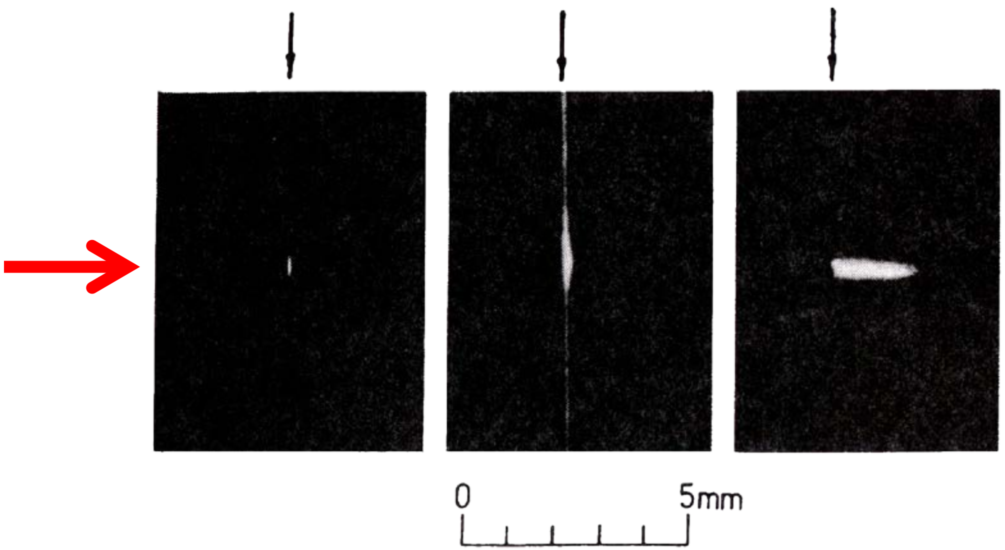

C. Grupen, *Teilchendetektoren*, B.I. Wissenschaftsverlag, 1993

# 3.4 Gas Counter Operation

## Different operation modes

Pictures comparing the gas discharge in a proportional counter, a Geiger-Müller counter and a streamer tube.

- Proportional counter (left): the discharge is located close to the anode wire only
- Geiger-Müller counter (middle): the discharge develops along the full wire
- Streamer tube (right): the development along the wire is suppressed, the discharge has a lateral extension and a much larger charge cloud compared to the proportional counter



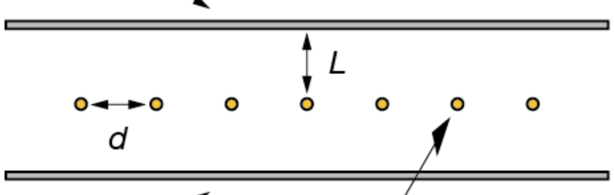

The black arrows indicate the position of the anode wire.

The red arrow indicates the impinging particle

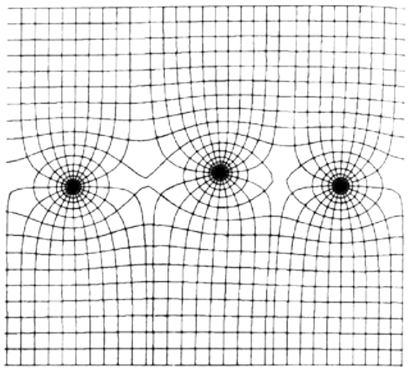
C. Grupen, *Teilchendetektoren*, B.I. Wissenschaftsverlag, 1993

# 3.5 Multi Wire Proportional Chamber (MWPC)

Geometry of a MWPC
(row of proportional counters without walls):




Electric field lines:




W.R. Leo, *Techniques for Nuclear and Particle Physics Experiments*, Springer, 1987

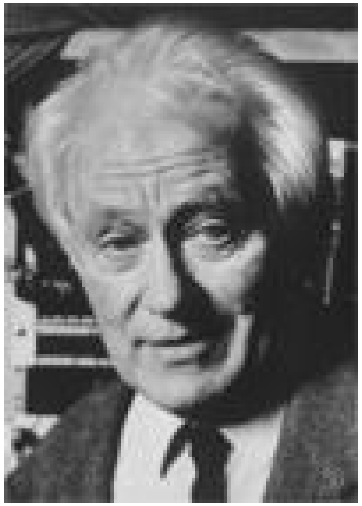
- ★ Diameter of anode wires 10 – 50 µm
- ★ Distances between wires 1 – 5 mm
- ★ Each wire connected to an amplifier
- ★ Typical gas amplification in MWPC is $10^5$
- ★ Max. particle rate ~10 kHz/mm$^2$

Position resolution:
Depends on wire distance
e.g. for d = 2 mm
By simply using the wire position

$$\sigma(x) = \frac{d}{\sqrt{12}} = 577\ \mu m$$

# 3.5 Multi Wire Proportional Chamber
## History

- MWPC was the first full electronic detector! Every anode wire is connected to an amplifier and the signals can be processed electronically.
- MWPC developed 1968 by Georges Charpak and others (R. Bouclier, F. Sauli, …).
- The Nobel Prize in Physics 1992 was awarded to Georges Charpak *"for his invention and development of particle detectors, in particular the multiwire proportional chamber"*.

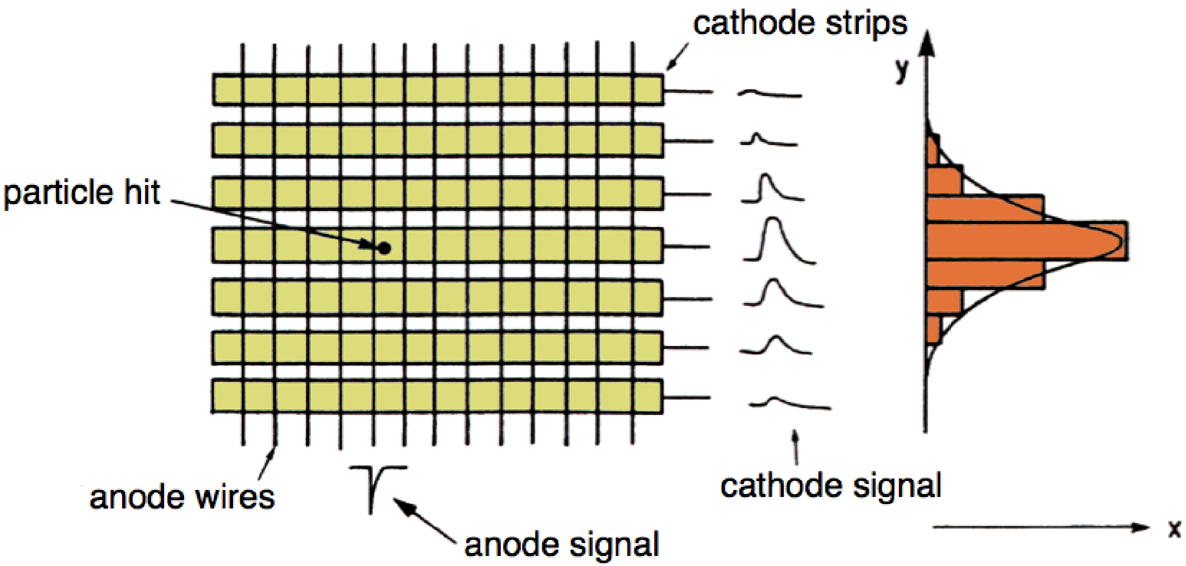


Georges Charpak (1924-2010)

Nobelprize.org
http://nobelprize.org/physics/laureates/1992/

# 3.5 Multi Wire Proportional Chamber
## Cathode Strip Chamber (CSC)

- A MWPC can only measure the coordinate perpendicular to the wires. No position measurement along the wires.
- If the cathode is segmented, perpendicular to the wires, the signal induced can be used to determine the second coordinate.
- Employing a center of charge calculation a position resolution of 50 µm is achievable.



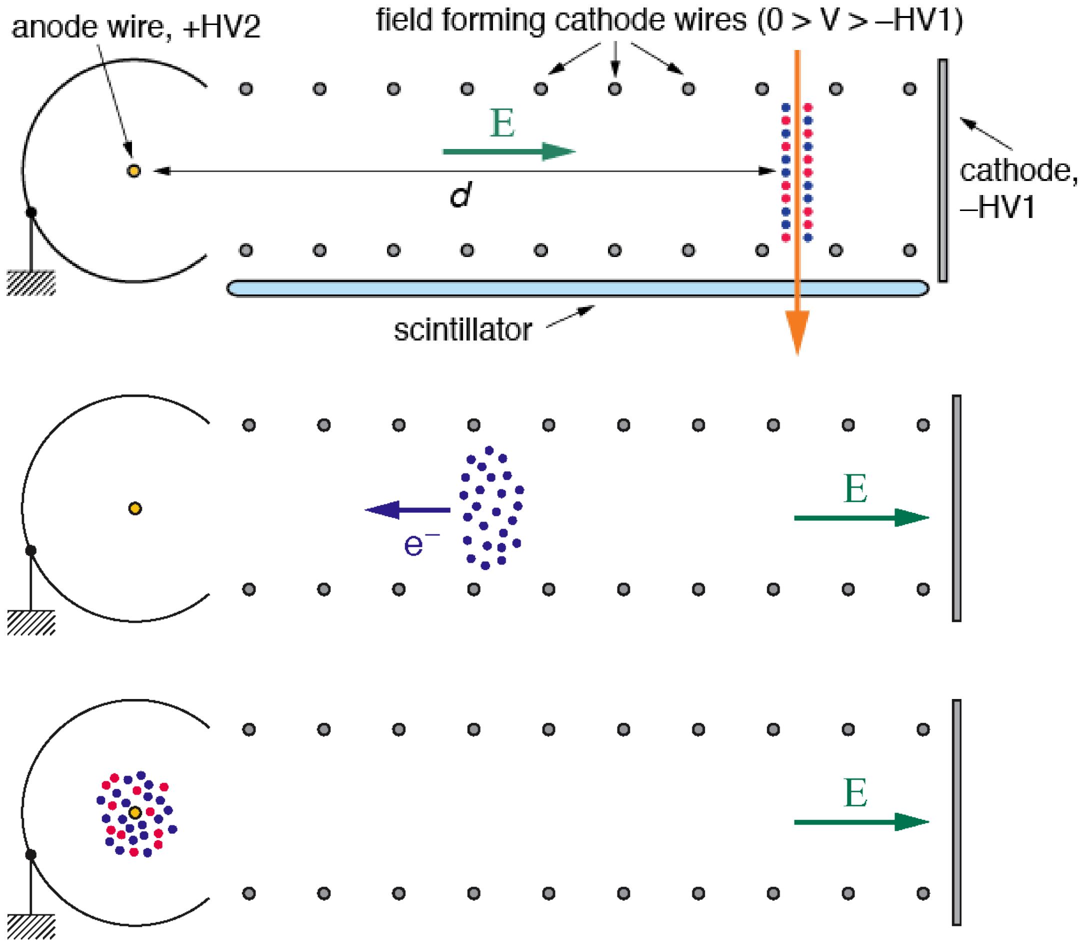

C. Grupen, *Teilchendetektoren*, B.I. Wissenschaftsverlag, 1993

## Principle

1. Charged particle traversing the chamber produce ionisation. The scintillator signal starts a timer ($t = t_0$).
2. Electrons drift to the anode wire.
3. Electrons reaching the wire create secondary ionisation (avalanche) and trigger a signal ($t = t_1$).

From the time difference the distance of the traversing particle to the wire is deduced.

$\Delta t = t_1 - t_0, \;\; x = v \cdot \Delta t$

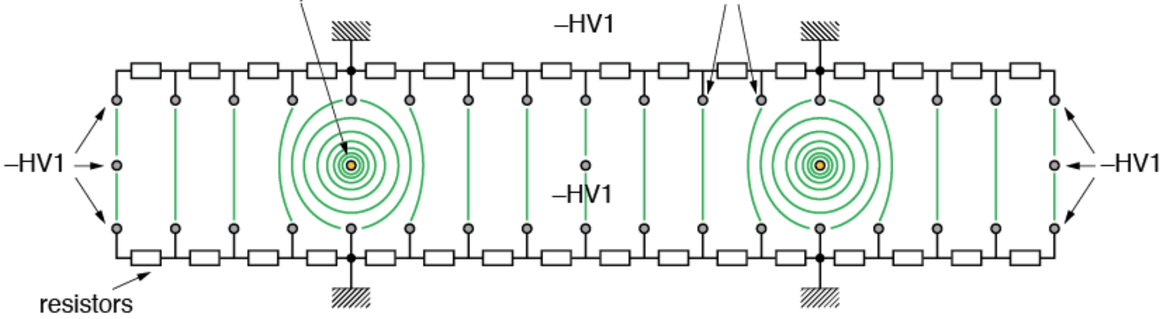


# 3.6 Drift Chambers (DC)
## Geometry and Properties

The electric field has to be homogeneous and the drift velocity constant and known.
Additional field wires can improve the homogeneity.

Typical geometry of a drift cell:

Typical drift distances 10 – 20 cm

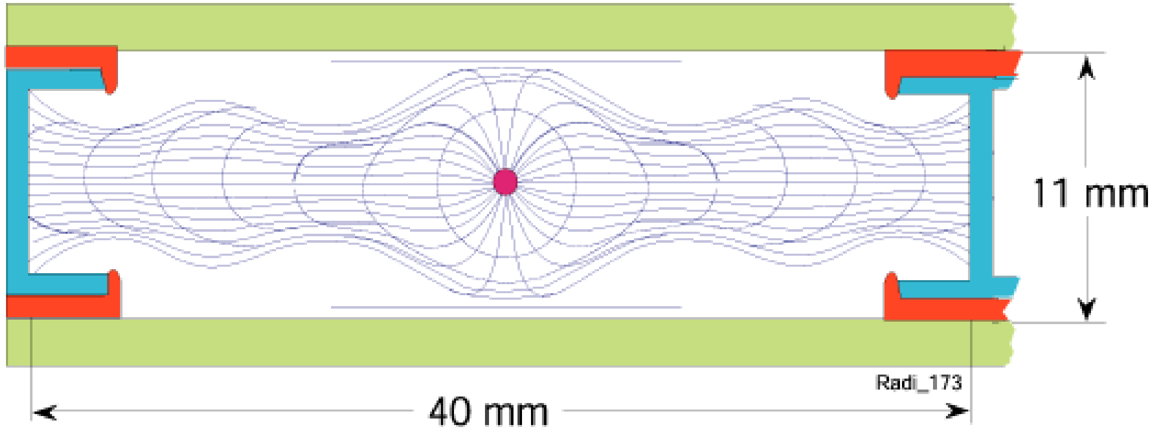



- ★ Position resolution for large area chambers ca. 200 µm (small chambers as good as 20 µm)
- ★ Various gases used. Distinguish between fast gases (high $v_D$ for high particle rates) and slow gases (low $v_D$ for high spatial precision).
- ★ Compared to MWPC: fewer wires and electronic channels, higher precision, but lower rate capability
- ★ Watch out for electronegative gas impurities.

# 3.6 Drift Chambers (DC)

## Example – The CMS Muon Chambers

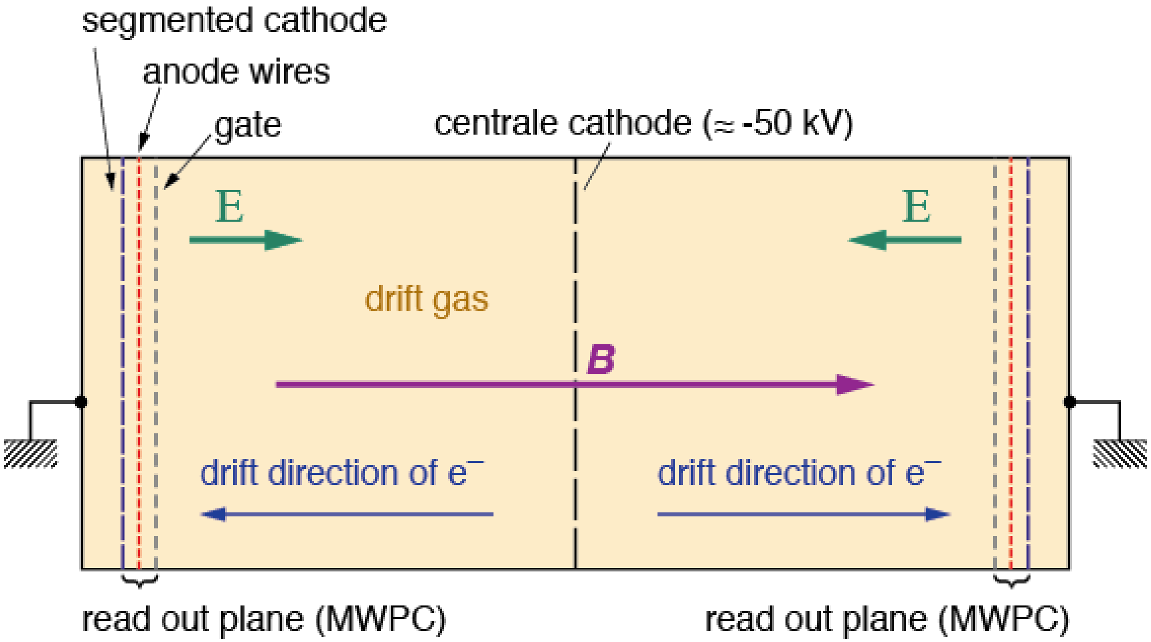
Cell geometry:



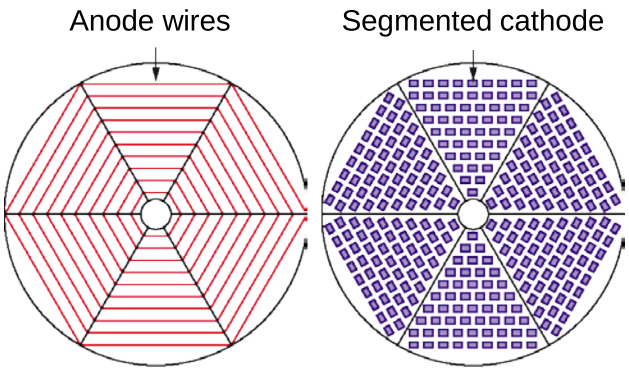

Chamber size 4 m x 2.5 m

4 chambers form a muon station

CERN, CMS Experiment



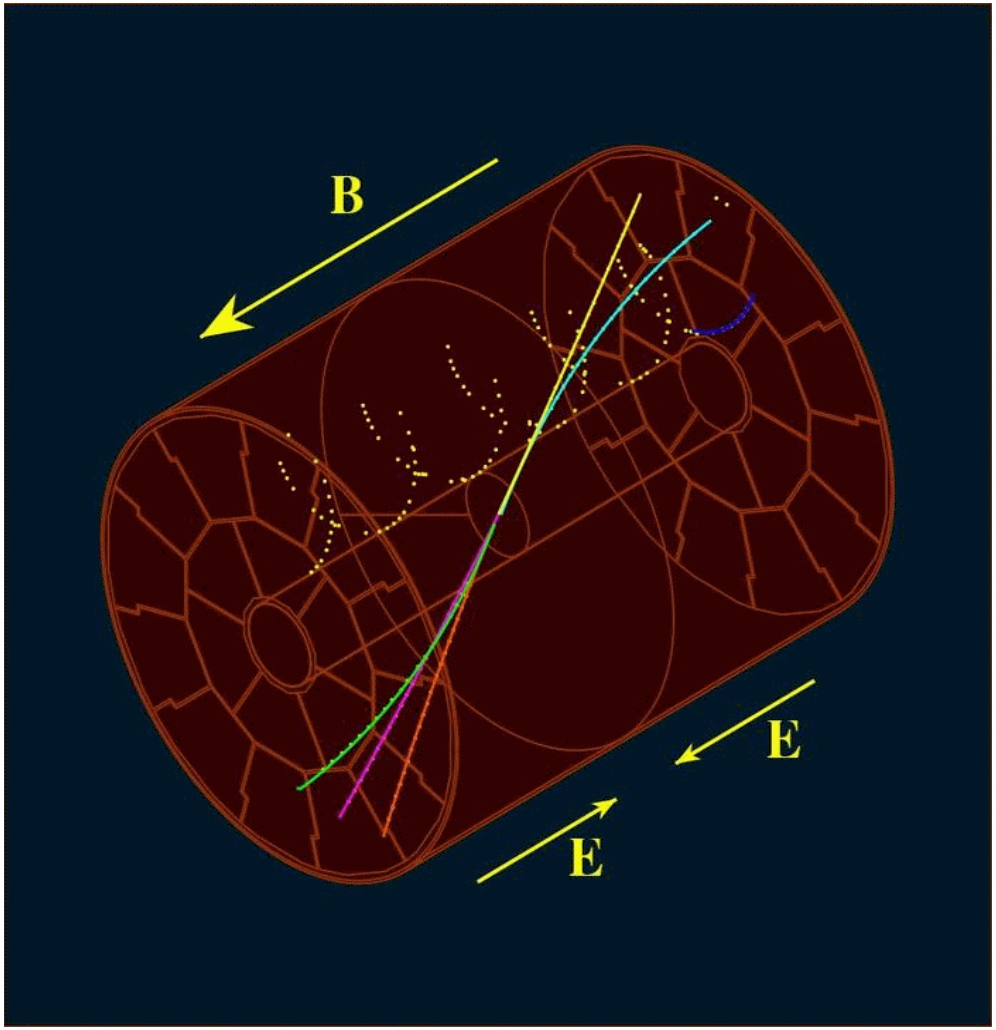

End plate detector (e.g. with segmented MWPC):




- ★ Big gas filled volume
- ★ Usually a central cathode at very high (negative) voltage in the middle
- ★ On both sides position detectors for 2 dimensions (end plates)
- ★ Electric field created by anode plane and central cathode plane parallel to the magnetic field of the experiment.

# 3.7 Time Projection Chamber (TPC)

## Principle




- ★ Charged particles create ionisation along the path.
- ★ Electrons drift to the end plates and ions to the central cathode.
- ★ A two dimensional projection of the particles path is measured by the position detectors at the end plates.
- ★ The third coordinate is deduced from the time of arrival of the electrons at the anode wires.

M. Titov, Präsentation VCI2007

# 3.7 Time Projection Chamber (TPC)

## Properties

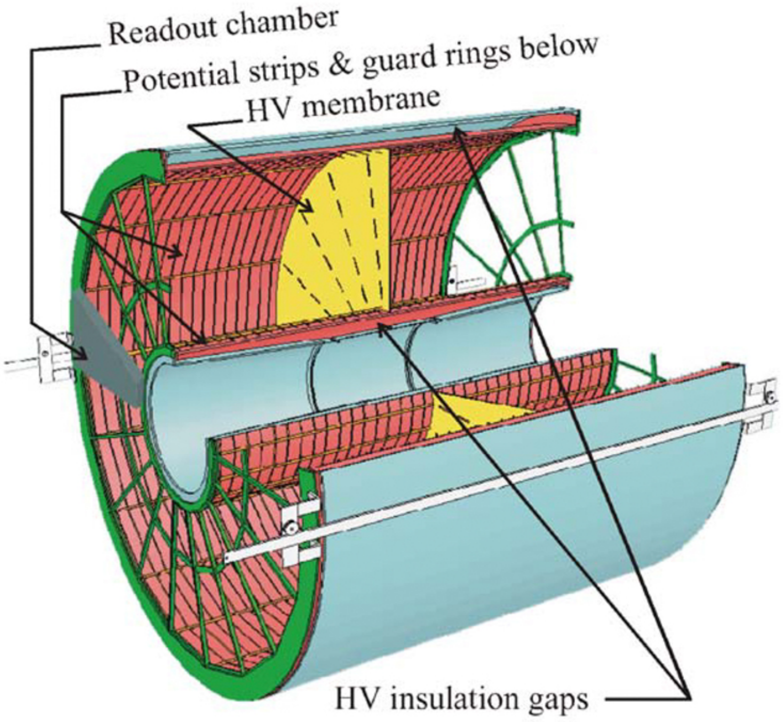
- ★ TPC covers a large volume and delivers three dimensional images of the particle track
- ★ Very little material involved (no wires in central volume)
- ★ Typical gas mixture argon:methane (e.g.: 9:1)
- ★ Up to a few hundreds of measurement points per particle track measured in large TPCs → excellent determination of the particle tracks (measurements also used for multiple dE/dx measurement → see chapter 7)
- ★ Position resolution of typically $\sigma_{r,\varphi}$ = 150–250 µm and $\sigma_z \approx$ 1 mm
- ★ Due to long drift times (e.g. 90 µs for 2,5 m drift length ALICE TPC), TPCs are not suitable for high particle rates.
- ★ Ions from end plate detector drift back into gas volume → long drift times and distortion of field due to space charge

  Additional wire layer (gate) between position detector and drift volume to stop positive ions is essential!

# 3.7 Time Projection Chamber (TPC)

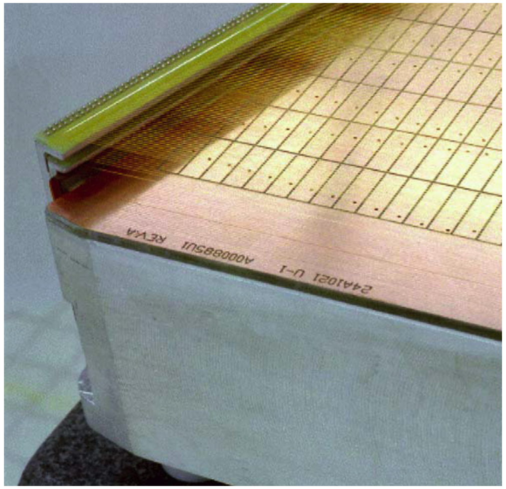
## Example - ALICE TPC, STAR TPC

Scheme of ALICE TPC (CERN):




M. Hoch, Nucl. Instr. Meth. A **535** , 1 (2004)

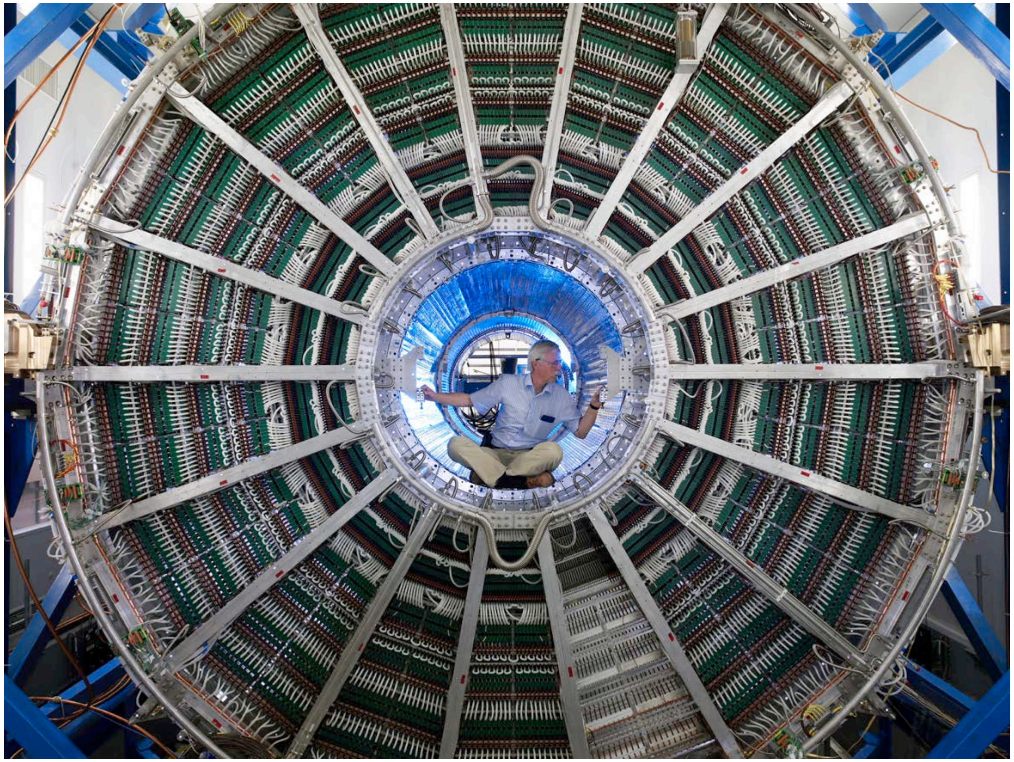
STAR TPC (BNL) end plate with MWPC. Visible is the segmented cathode:



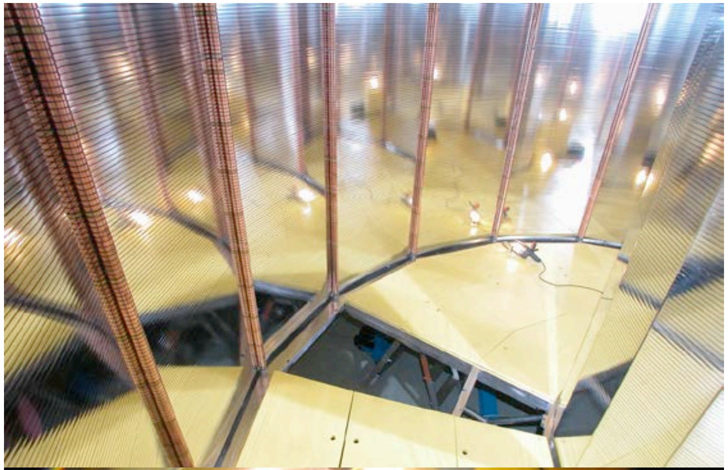
# 3.7 Time Projection Chamber (TPC)

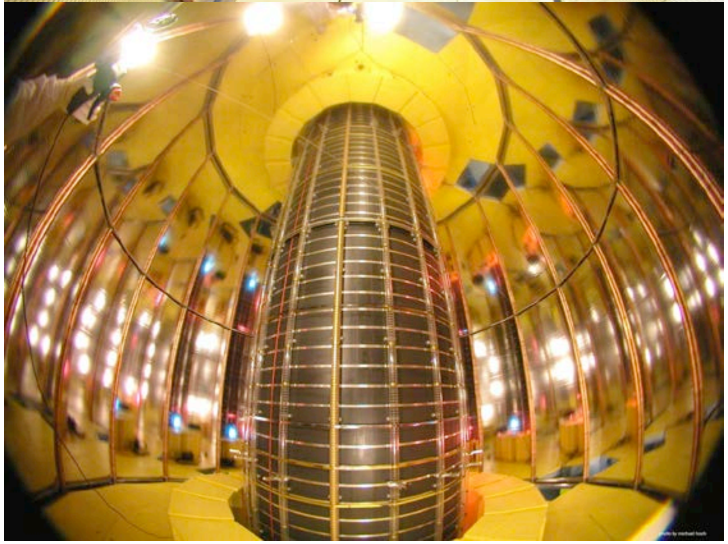
## Example - ALICE TPC

The ALICE TPC (CERN):



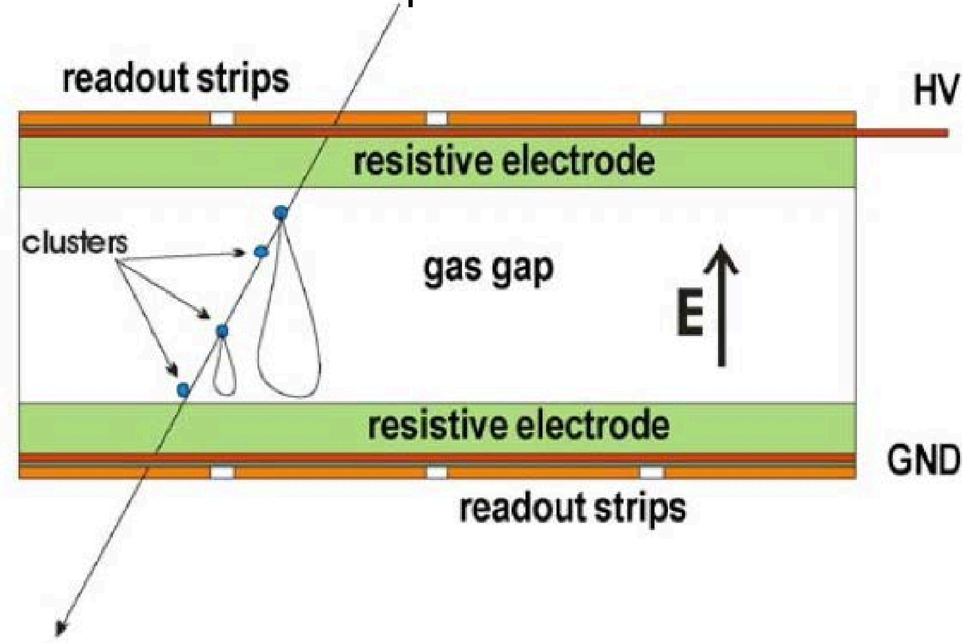
CERN Photo Database





# 3.8 Resistive Plate Chambers
## Construction

- ★ Gas gap typically 2 mm
- ★ resistive electrodes made of bakelite (phenolic resin) plates covered with a thin layer of melamine
- ★ electrodes to apply high voltage and insulated pick up electrodes
- ★ Gas chambers operated in avalanche or streamer mode.

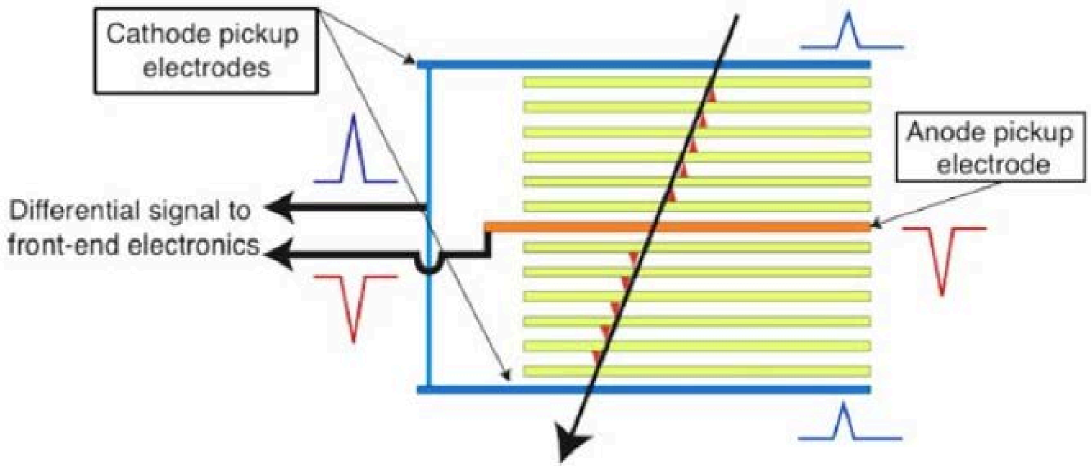



M. Hoch, Nucl. Instr. Meth. A **535**, 1 (2004)

Large area detectors
Space resolution ~ mm
Very fast timing (~ 1 ns) and sufficient high rate capability (~ 100 Hz/cm$^2$)
➔ ideal devices for trigger detectors

# 3.8 Resistive Plate Chambers
## Multi gap chambers

- ★ Pile of resistive gas plates separated by thins spacers (~250 µm, e.g. nylon fishing lines)
- ★ High voltage is applied to the outer electrodes, internal plates are floating and get correct potential by electrostatic equilibrium




M. Hoch, Nucl. Instr. Meth. A **535**, 1 (2004)

Very high efficiencies
Time resolution as low as 50 ps

Used for example in the ALICE TOF chambers.

# 3.9 Micro Pattern Gas Detectors (MPGD)

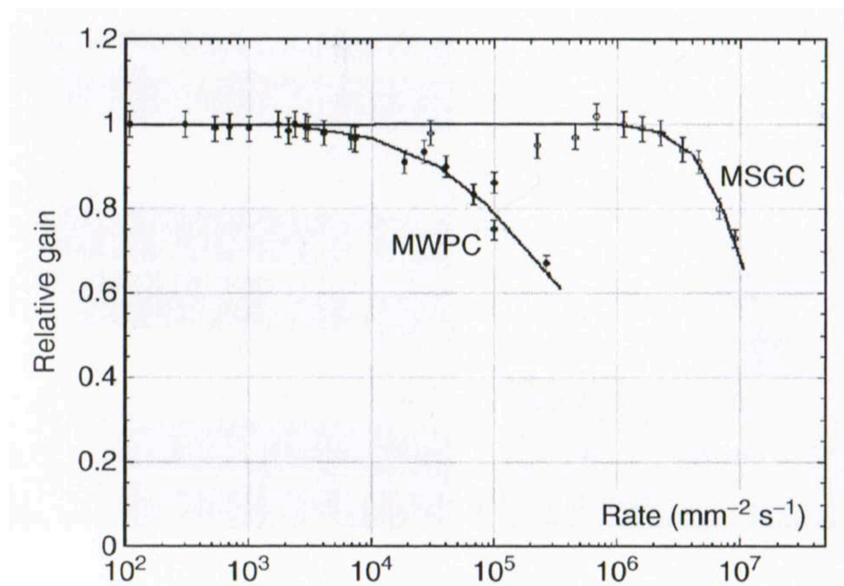
Large group of different detector geometries

★No wires – electrodes are deposited materials or printed structures. Photolithography of these processes allow for very fine structures.

★Smaller cell sizes → improved position resolution ~ 30 µm
→ high rate capability ~ MHz/mm$^2$

Examples shown in this chapter:

- ★ Micro Strip Gas Counter
- ★ GEM
- ★ Micromegas




(MWPC) A. Breskin et al., Nucl. Instr. Meth. A **124** (1975)
(MSGC) A. Barr et al., Nucl. Phys. B **61B** (1998)

# 3.9 Micro Pattern Gas Detectors

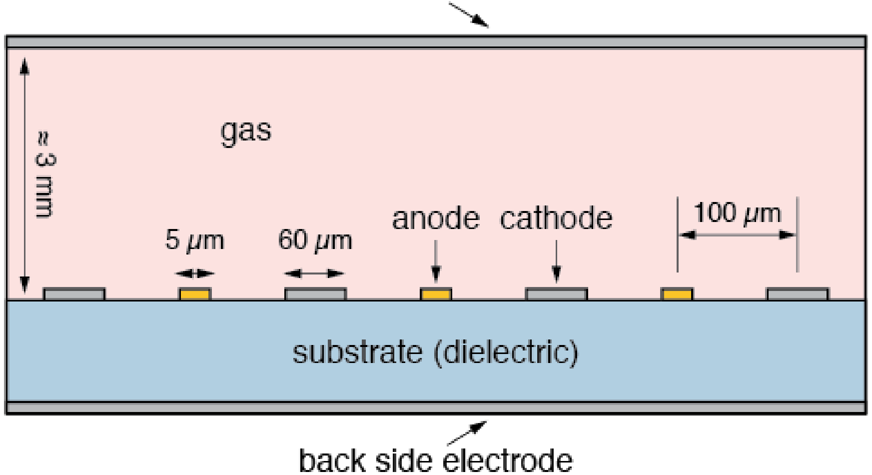
## Micro Strip Gas Counter (MSGC)

First MPGC developed.

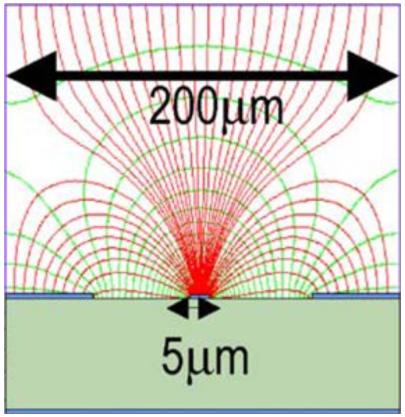
★ Thin anode and cathode strips deposited onto a substrate (glas, ceramic, plastic), Cathode strips improve the field geometry.

★ Gas volume above the detector plane

MSGC scheme:




Field lines in a MSGC cell (anode wire in the middle):




M. Hoch, Nucl. Instr. Meth. A **535** , 1 (2004)

★ A weak point of MSGC is the radiation resistance, gas multiplication process damages the thin structures

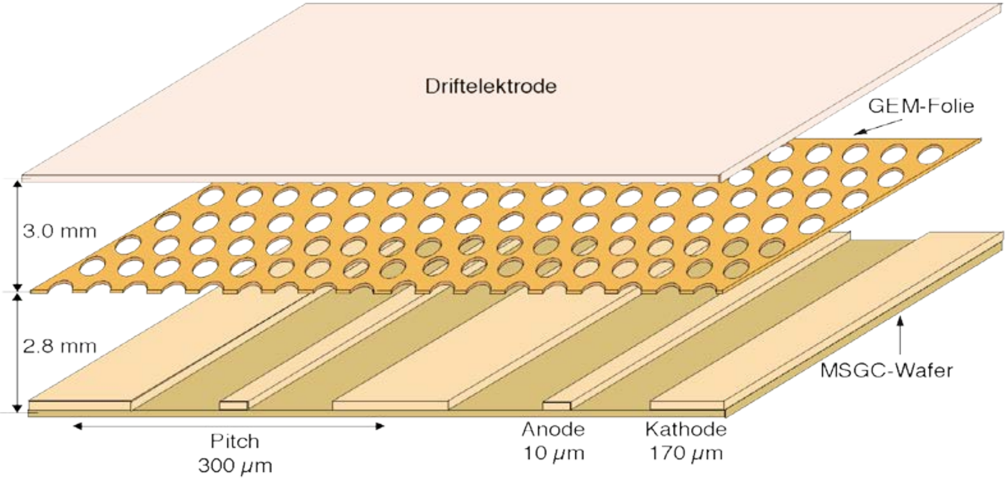
## Gas Electron Multiplier (GEM)

Improve radiation resistance by separating amplification and detection structures:

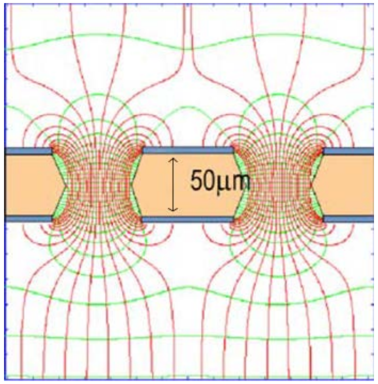
★ The gas volume is separated into a drift gap and an induction gap by a GEM foil. A MSGC plane is underneath.

★ The foil (e.g. 50 µm thickness) is metalized on both sides and has a pattern of holes (e.g. 70 µm with a 140 µm pitch).

★ A high voltage (~ 400 V) applied on the two faces of the foil creates a high field inside the holes → electron multiplication takes place in the holes




Field lines in a GEM foil:

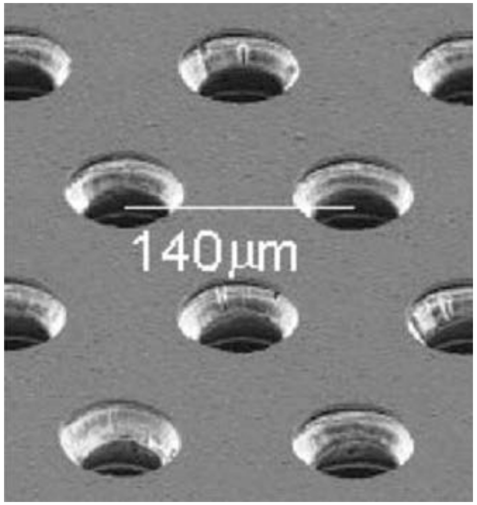



M. Hoch, Nucl. Instr. Meth. A **535** , 1 (2004)

# 3.9 Micro Pattern Gas Detectors

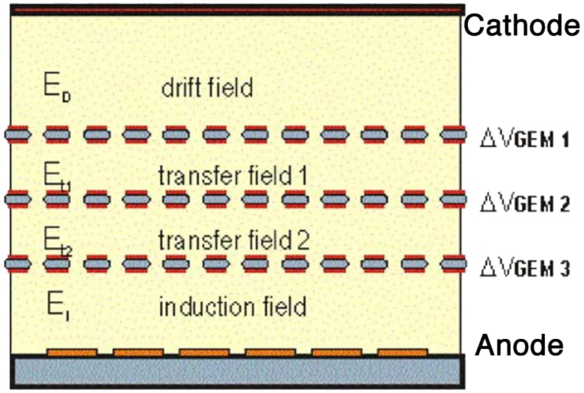
## Gas Electron Multiplier (GEM)

Microscope view of a GEM foil:




F. Sauli holding a GEM foil:


Scheme of a triple GEM detector:



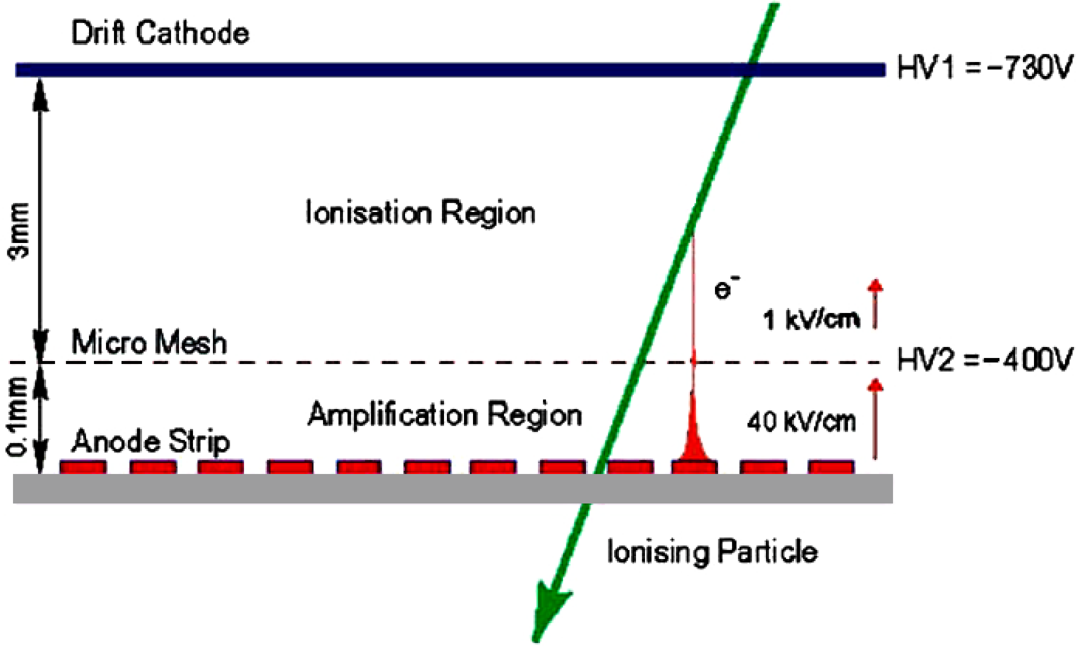

Amplification in triple GEMs up to $10^5$

M. Hoch, Nucl. Instr. Meth. A **535** , 1 (2004)

# 3.9 Micro Pattern Gas Detectors

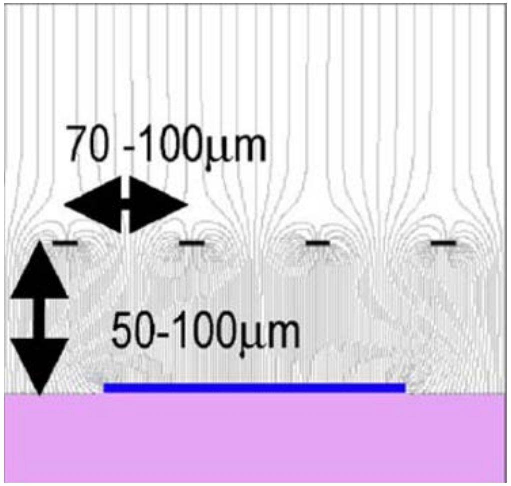
## MICROMEGAS

- ★ A metallic micro mesh separates the drift volume (2 – 5 mm thick) from the amplification volume (50 – 100 µm thick).
- ★ The positive ions drifting back from the anode strips are collected (and removed) by the mesh → fast detector




M. Hoch, Nucl. Instr. Meth. A **535** , 1 (2004)

Field lines:



- End.

# 3.1 Basic Principles
## Important gas parameters

Important gas parameters are:

★Ionisation energy $I_0(eV)$

★Energy loss required to produce an electron ion pair $W_i(eV)$
$\rightarrow$ app. 30 eV

Part of the energy is lost to excite the medium. Noble gases are preferentially used due to the absence of vibration and rotation states
➔ ionisation dominates.

★Total number of produced electron ion pairs for a mip per path length $n_t$

★Number of primary electrons reduced by

- recombination $A^+ + e^- \rightarrow A + \gamma$
- $e^-$ attachment $A + e^- \rightarrow A^- + \gamma$

# 3.1 Basic Principles
## Important Gas Parameters - Examples

| Gas | $\rho$ (g/cm$^3$) (STP) | $I_0$ (eV) | $W_i$ (eV) | $dE/dx$ (MeVg$^{-1}$cm$^2$) | $n_t$ (cm$^{-1}$) |
|---|---|---|---|---|---|
| $H_2$ | $8.38 \cdot 10^{-5}$ | 15.4 | 37 | 4.03 | 9.2 |
| He | $1.66 \cdot 10^{-4}$ | 24.6 | 41 | 1.94 | 7.8 |
| $N_2$ | $1.17 \cdot 10^{-3}$ | 15.5 | 35 | 1.68 | 56 |
| Ne | $8.39 \cdot 10^{-4}$ | 21.6 | 36 | 1.68 | 39 |
| Ar | $1.66 \cdot 10^{-3}$ | 15.8 | 26 | 1.47 | 94 |
| Kr | $3.49 \cdot 10^{-3}$ | 14.0 | 24 | 1.32 | 192 |
| Xe | $5.49 \cdot 10^{-3}$ | 12.1 | 22 | 1.23 | 307 |
| $CO_2$ | $1.86 \cdot 10^{-3}$ | 13.7 | 33 | 1.62 | 91 |
| $CH_4$ | $6.70 \cdot 10^{-4}$ | 13.1 | 28 | 2.21 | 53 |
| $C_4H_{10}$ | $2.42 \cdot 10^{-3}$ | 10.8 | 23 | 1.86 | 195 |

K. Kleinknecht, *Detektoren für Teilchenstrahlung*, B.G. Teubner, 1992